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Numerical analysis of devices for de-icing electrical lines and ground cables

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This report summarises research and development work done under Contract BDA0152, "Numerical Simulation of an Explosive Impactor for De-Icing Arial Electric Lines and Guard Cables" carried out for Hydro Québec, Varennes, Québec, Canada.

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Abstract

This report summarises numerical analyses performed to predict the responses of Hydro Québec's piston/cylinder prototype and an explosive flyer plate concept that were both investigated for the de-icing ground cables and electrical lines. In the piston/cylinder prototype case, the numerical results obtained compared very well with the experimental results obtained from Hydro Québec. It was shown that the maximum cable displacement decreases as the static pre-tension value is increased. In all cases it was shown that the maximum cylinder displacement remained independent of the cable tension. The negative slope observed in the experimental velocity/time results after the cable has reached its maximum velocity was also captured quite well in the simulations. It was shown that this negative slope was caused by the increase in the mechanical impedance, which was due to the dynamic effect on the static tension. In the case of the explosive concept, the numerical results showed that it is feasible to use such a system to de-ice cables. Comparisons of the results with those of the piston/cylinder prototype show that the cable responds more rapidly using the explosive concept. For the explosive concept it was found that the maximum displacement of the cable varies linearly with the mass of explosive.

Résumé

Ce rapport résume les analyses numériques utilisées pour prédire la réponse du prototype piston/cylindre d'Hydro Québec et d'un concept d'une plaque explosive pour le déglaçage des câbles de garde et des lignes électriques. Dans le cas du prototype, les résultats numériques concordent très bien avec les résultats expérimentaux d'Hydro Québec. Il a été démontré que le déplacement maximum du câble diminue avec la diminution de la tension statique du câble. Dans tous les cas, il a également été constaté que le déplacement maximum du cylindre était indépendant de la tension statique du câble. La pente négative observée dans les résultats expérimentaux de la vitesse en fonction du temps a très bien été montrée par les simulations. Il a été observé que la pente négative était causée par une augmentation de l'impédance mécanique due à l'effet dynamique sur la tension statique. Dans le cas du concept de plaque explosive, les résultats numériques montre que ce concept fonctionne pour déglacer les câbles. Comparaison des résultats de plaque explosive avec ceux du prototype piston/cylindre montre que le câble répond plus rapidement lorsque le concept explosif. Il a été montré que le déplacement maximum dans le concept de plaque explosive varie linéairement en fonction de la masse d'explosif.

Executive summary

The Warren Commission on the 1998 ice storm recommended that Hydro Québec implement a research and development aimed at finding a method of de-icing electric lines and resolve the problem of the failure of ground cables which can lead to the collapse of supporting structures. In November 2000, the Defence Research Establishment Valcartier (DREV) was contracted by Hydro-Quebec to investigate the possibility of developing a small, simplified, inexpensive, portable explosive device, which once installed on the ground cables could be detonated remotely. To start the investigation of new explosive devices, DREV and Hydro-Québec mutually decided to first conduct numerical simulations of the cylinder/piston device that Hydro-Québec developed and tested. This aspect was necessary mainly to verify that the numerical simulation was capable of reproducing the correct cable response and that of the cylinder and piston.

Numerical simulations of Hydro Québec's piston/cylinder prototype de-icing device were conducted. The numerical results compared very well with the experimental values and the effect of the cable's pre-tension conditions were also captured extremely well. The results showed that the maximum cable displacement decreases as the magnitude of the static tension is increased. The results further showed that as the magnitude of the static pre-tension is increased the negative slope in the velocity curve is also increased which indicates that mechanical impedance of the cable must have also increased. In all cases the maximum displacement of the cylinder was self-determining of the magnitude of the static pre-tension value as would be expected.

Simulations were also conducted on an explosive concept for de-icing ground cables using a limited mass of explosive called Detasheet. Three thicknesses of Detasheet were used. The numerical results showed that it is possible to displace the cable as much as in the case of the cylinder/piston prototype. It was found that the maximum cable displacement varies linearly with the explosive mass. Comparison of the results from the piston/cylinder prototype and the explosive concept shows that the piston/cylinder responds less rapidly than the explosive concept. In the piston/cylinder case it was observed that the cable displacement varies almost linearly up until it reaches its maximum. On the other hand, in the explosive case, the displacement increases rapidly within the first 6 to 10 ms after which it slowly levels off at its maximum displacement.

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Le rapport des experts de la commission Warren sur le tempête de verglas de 1998 a recommandé qu'Hydro Québec mettre en oeuvre un programme de recherche et développement visant à trouver une méthode de déglaçage des linges électriques et à résoudre la problème de rupture des câbles de mise à la terre qui peuvent entraîner la destruction de la structure de support. En novembre 2000, le centre de recherche de la défense Valcartier (CRDV) a été engagé par Hydro Québec pour examiner la faisabilité d'un petit appareil explosif, peu coûteux et portatif qui une fois installer sur le câble de mise à la terre, peut être détoné à distance. Afin d'initier le développement du nouveau concept explosif le CRDV et Hydro Québec ont mutuellement décidé de débuter par la simulation du système de cylindre/piston qu'Hydro Québec à développé et expérimenté. Cette étape est nécessaire pour vérifier la capacité de simulation numérique à reproduire correctement la réponse du câble et ceux du système cylindre/piston.

Ainsi, des simulations numériques du prototype de système de déglaçage cylindre/piston d'Hydro Québec ont été exécutées. Les résultats numériques concordent très bien avec les valeurs expérimentales et l'effet de la tension du câble est également bien montré. Les résultats indiquent que le déplacement maximal diminue pendant que la tension statique augmente. Les résultats ont aussi démontré que la pente négative de la courbe vitesse/temps augmente en fonctionne de l'intensité de la tension statique. Ce fait indique que l'impédance mécanique augmente également. Dans tous les cas le déplacement maximal du cylindre reste indépendant de l'intensité de la tension statique tel que prévu.

Des simulations du concept explosif pour déglacer les câbles de mise à terre ont aussi été exécutées en utilisant une masse d'explosive restreint appelé Detasheet. Trois épaisseurs d'explosif ont été utilisées. Les résultats ont démontré qu'il est possible de déplacer le câble de façon comparable au prototype cylindre/piston. De plus, on a trouvé que le déplacement maximal du câble varie linéairement en fonction de la masse d'explosif. La comparaison des résultats du prototype du cylindre/piston avec ceux du concept d'explosif ont démontré que le cylindre/piston répond moins rapidement que le système explosif. Dans le cas du cylindre/piston, il a été observé que le déplacement du câble varie approximativement linéairement jusqu'à ce qu'il atteigne le maximum. Dans le cas du système d'explosif, le déplacement du câble augmente rapidement pour les primaires 6 à 10 ms, suivi d'une progression lente jusqu'au déplacement maximal.

Nandlall, D., Sidhu, R. 2001. Numerical analysis of devices for de-icing electrical lines and ground cables. DREV ECR 2001-198. Centre de recherche pour la défense Valcartier.

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Introduction

The consequences of ice formation on overhead conductors and ground wires are extremely important in terms of accidents and material damage. The ice storm of 1998 demonstrated the need for de-icing electrical lines, especially ground wires. The ice storm caused extensive material damage and placed many people's lives in danger as several communities were without power for many weeks during the middle of winter. The Warren commission on the 1998 ice storm recommended that Hydro-Québec implement an aggressive research and development programme aimed at, among other things, finding a method of de-icing electric lines and resolving the problem of the failure of ground wires leading to the collapse of the supporting structures under the heavy weight of the ice.

In response to the Warren commission report, Hydro-Québec (Ref. 1) implemented a very proactive program aimed at de-icing electrical lines and ground wires during winter. Within this program, Hydro-Québec developed and conducted extensive experimental tests on a propulsive system that could be used to de-ice ground wires (Ref. 1). The de-icing device is basically comprised of a cylinder and a piston using a 12-gauge cartridge to propel the piston towards the cable. This 11.2-kg device, once fired, applies an impulsive shock loading to the ice-covered cable. The cylinder/piston device is portable and needs to be installed on the cable, fired from a distance and recovered from the cable. This is an expensive process. SNC TEC (Ref. 2) conducted some characterisation work and a review of the Hydro Québec cylinder/piston device. A preliminary study of the propulsion system was conducted and recommended that an interior ballistics code be used to optimise the device. An evaluation of the use of the hydrocode LSDYNA was conducted but no conclusions were made. It was recommended that further studies were needed to determine the feasibility of the use of LSDYNA to numerically investigate the prototype design.

In November 2000, Hydro-Quebec contracted the Defence Research Establishment Valcartier (DREV) to investigate the possibility of developing a small, simplified, inexpensive, portable explosive device which once installed could be detonated remotely. After the loading was applied to the cable, the device would self detach and falls to the ground. The development of such an explosive device could be long and expensive. To accelerate the process, DREV proposed a feasibility study using numerical simulations via a hydrodynamic finite element shock code. Numerical techniques offer a relatively inexpensive and efficient means of evaluating the potential of new designs.

To start the investigation of new explosive devices, DREV and Hydro-Québec mutually decided to first conduct numerical simulations of the cylinder/piston device that Hydro-Québec developed and tested. This aspect is necessary mainly to verify that the numerical simulation was capable of reproducing the correct response of the cylinder, piston and cable.

Objective

The objective of the work presented in this report was to conduct numerical simulations of Hydro Québec's cylinder/piston de-icing device and to compare the numerical results with experimental results obtained from tests conducted by Hydro Québec. In addition, once it was established that the guard cable response to the impact loading by the piston could be modelled correctly, numerical simulations were to be used to explore the possibility of developing a small explosive de-icing device to be used on guard cables.

Numerical modelling

The LSDYNA3D hydrodynamic computer code (Ref. 3) is an explicit/implicit three dimensional finite element code used for analysing large deformation and dynamic response of solids and structures. It was applied to the analysis of the transient response of Hydro-Québec's de-icing device impacting a 12.7-mm diameter ground wire.

1.1 Hydro-Québec's de-icing device

Figure 1 shows an exploded view of Hydro-Québec's de-icing device. It consists mainly of a cylinder and piston with a 12-gauge cartridge fire mechanism. The piston is attached to a sleeve, which is fixed around the half-inch diameter steel cable.

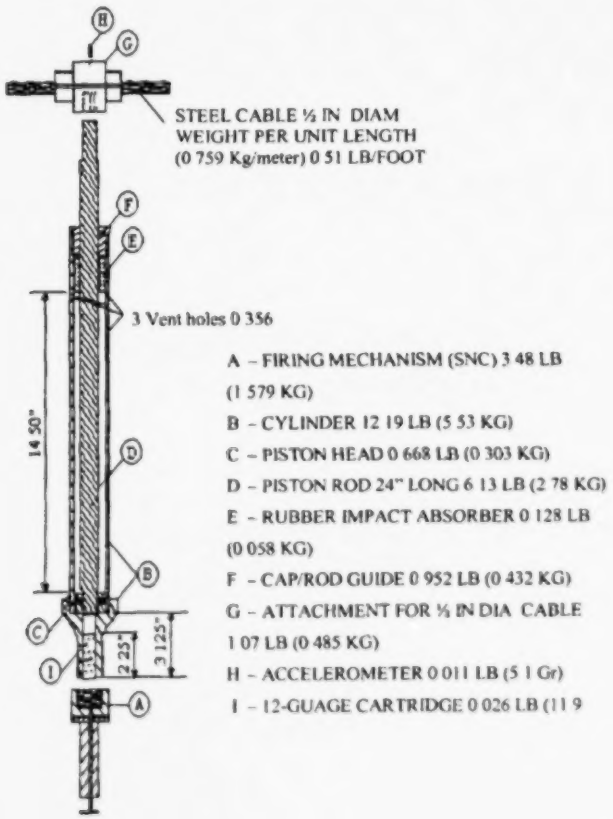

STEEL CABLE ½ IN DIAM
WEIGHT PER UNIT LENGTH
(0 759 Kg/meter) 0 51 LB/FOOT
3 Vent holes 0 356
14 50"
2 25"
3 125"
A – FIRING MECHANISM (SNC) 3 48 LB
(1 579 KG)
B – CYLINDER 12 19 LB (5 53 KG)
C – PISTON HEAD 0 668 LB (0 303 KG)
D – PISTON ROD 24" LONG 6 13 LB (2 78 KG)
E – RUBBER IMPACT ABSORBER 0 128 LB
(0 058 KG)
F – CAP/ROD GUIDE 0 952 LB (0 432 KG)
G – ATTACHMENT FOR ½ IN DIA CABLE
1 07 LB (0 485 KG)
H – ACCELEROMETER 0 011 LB (5 1 Gr)
I – 12-GUAGE CARTRIDGE 0 026 LB (11 9

Figure 1. *Exploded view of the Hydro-Québec's de-icing device*

1.2 Numerical mesh of Hydro-Québec's de-icing device

To model the dynamic response of the piston/cylinder impactor and the subsequent transient deformation of the 12.7-mm diameter ground wire it was necessary to divide the entire region into a number of regions called elements. The network of elements obtained is called a mesh. The computations were then performed, solving the constitutive equations that describe the relationship between the forces and the displacements in the materials. Figure 2 shows the global finite element mesh that was used for the simulations. This mesh was considered as the initial state. At time 0 ms, the cartridge was fired. Due to the bilateral symmetry of the problem, only half of the domain had to be considered. In this case the length of the ground wire modelled was 5.0 m.

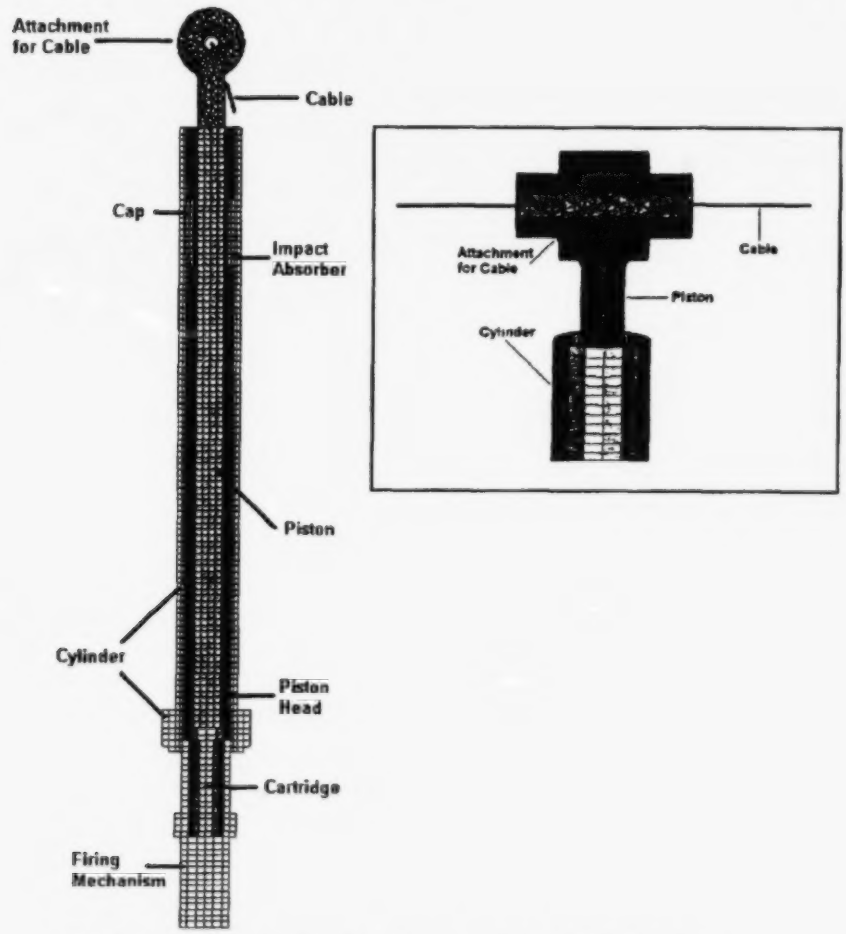


Figure 2. *Finite element model of Hydro-Québec's de-icing device*

Table 1 shows the element distribution for the various parts of the de-icing device and the cable. 8-node brick and 4-node tetrahedral elements were used throughout the mesh for the de-icing device. Beam elements with circular cross sections were used for the cable.

Table 1. *Element distribution and numerical and prototype mass comparison*

Part	# of Elements	Element Type	Model Mass (kg)	Prototype Mass (kg)
Piston Rod/ Piston Head	2358	Brick / Tetrahedron	3.089	3.083
Attachment/ Accelerometer	1251	Tetrahedron	0.497	0.491
Cap/ Impact Absorber	544	Brick	0.480	0.490
Cylinder/ Firing Mechanism	2198	Brick	7.13	7.12
De-icing Device Total mass	-	-	11.196	11.184
Steel Cable	5000	Beam, w/ Circular Cross-section	0.759 kg/m	0.759 kg/m

1.3 Material description

For all the simulations, kinematic/isotropic elastic-plastic hydrodynamic materials were used for both the cylinder and cable. This model assumes a bi-linear stress-strain behaviour while any strain rate dependency is accounted for very simplistically through a scaling factor applied to the yield stress. The parameters used for the different materials are shown in Table 2. The frictional forces between the materials in contact were not modelled. It was assumed that the large pressure dominates the effects of the other forces during the transient response, and therefore, the frictional forces between materials were negligible.

Table 2. Material properties used for the piston/cylinder prototype system

Material Property	Cylinder / Piston Components (Steel)	Attachment for Cable (Aluminium)	Cable (Steel)
Density, ρ (g/cm^3)	7.83	2.768	5.99
Elastic modulus, E (MPa)	197500	73080	197500
Poisson's ratio, ν	0.3	0.34	0.3
Yield stress, σ_y (MPa)	1320	335	1320
Tangent modulus, E_t (MPa)	1810	646	1810
Failure Strain, f_s	2.0	1.0	2.0

1.4 Boundary and loading conditions

1. Static tension modelling

As shown in Fig. 3, the cable tension, T, is applied along the axis of the cable. Modelling the cable tension involved applying a pre-stress condition equivalent to the static tension loading. In this study, the response of the piston and cylinder was examined for values of T ranging from 0 to 24 kN.

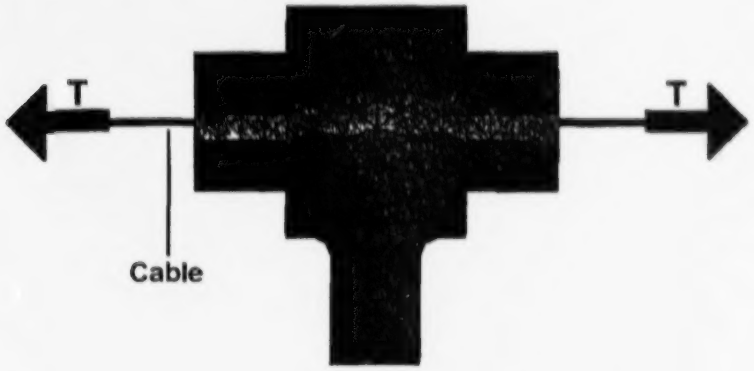


Figure 3. Application of static tension, T, to the cable

2. Cartridge chamber pressure loading

Figure 4 shows the pressure-time history measured in the cartridge chamber during experiments conducted by Hydro-Québec. This pressure-time history curve was applied as loading conditions to both the piston and the cylinder.

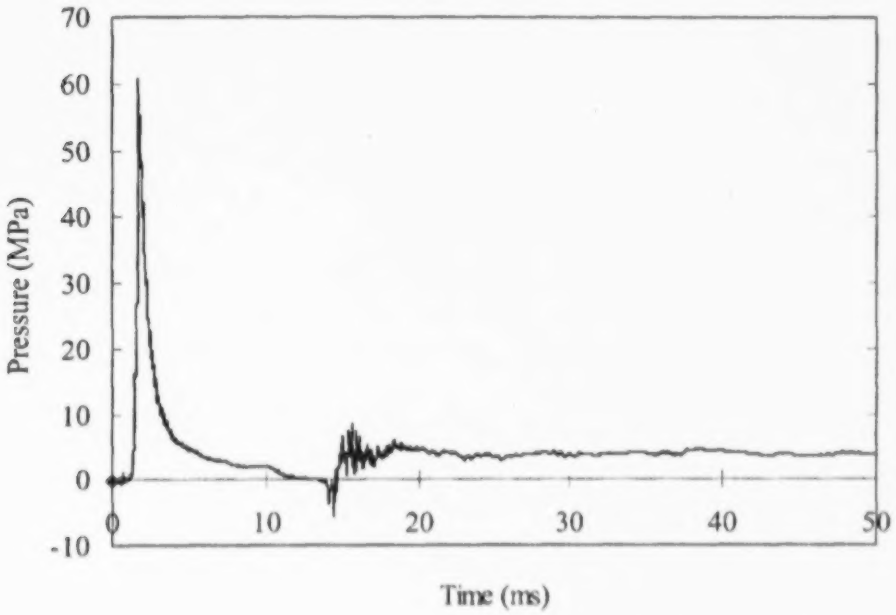


Figure 4. *Cartridge Chamber Pressure-Time Curve to be used as the loading condition*

Computational results for the piston/cylinder de-icing prototype

Figure 5 shows a typical example of a simulation that was performed in an effort to obtain the ice-free cable response to the impact loading of the de-icing device. Figure 6 shows the final piston position in the cylinder using in a bi-symmetrical section.

Figure 5. *Typical simulation performed to examine the cable response to the impact from the de-*

icing device

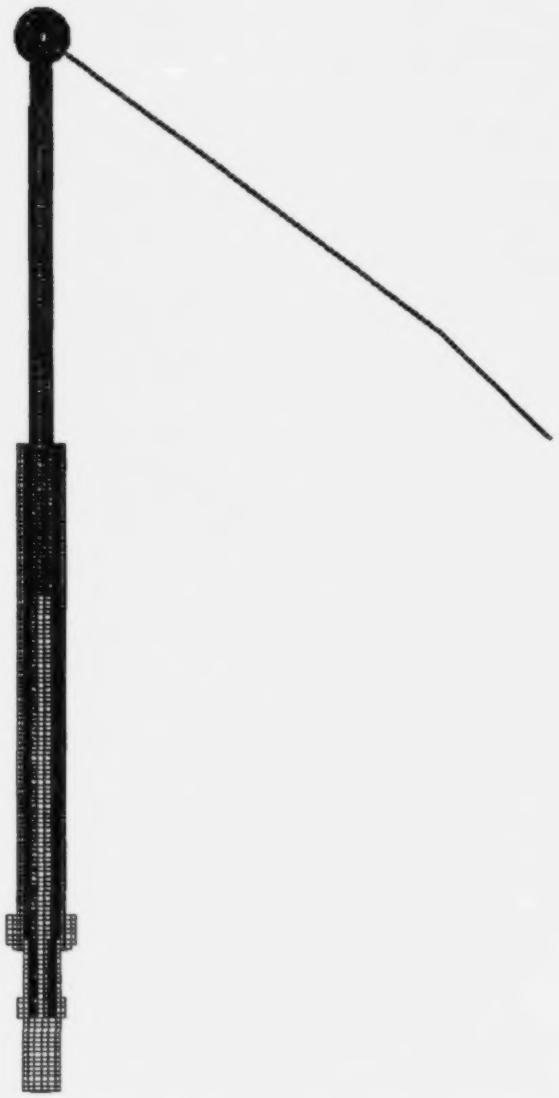
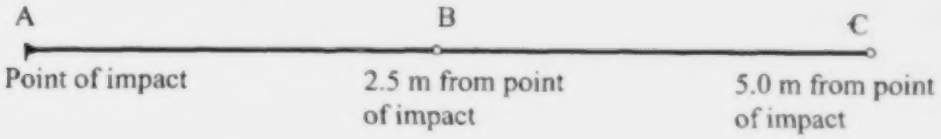


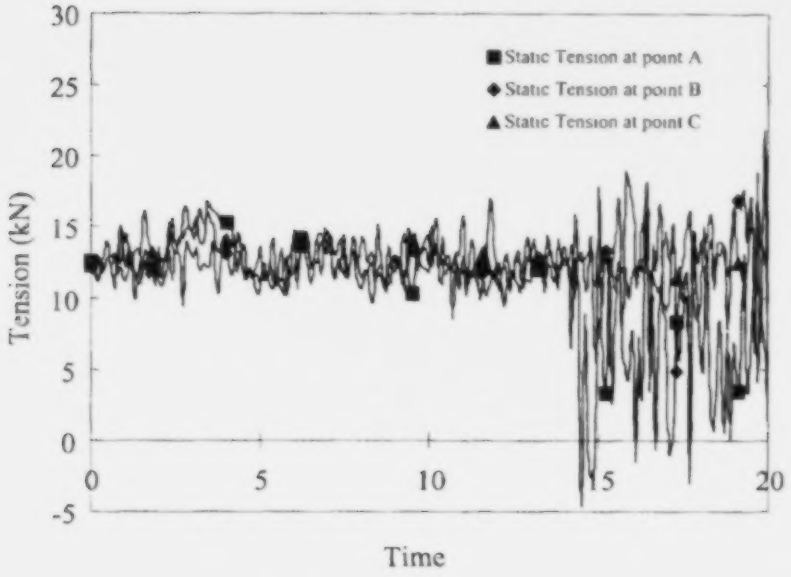
Figure 6. *Bi-symmetrical section of the de-icing device showing the piston, cylinder and cable position*

Figure 7 (a) shows three points A, B and C along the axial direction of the cable. Figure 7 (b) shows the axial tension, T, of the cable as a function of time at the three points A, B and C. For this case, the pre-tension value is 12.5 kN. As could be seen the

effect on the cable tension due to the dynamic loading by the piston was captured quite well by the numerical model especially at about 15 ms when the cylinder had reached its maximum course along the piston length.



(a)



(b)

Figure 7. *Variation of the axial tension, T, as a function of time at points A, B and C along the axial direction of the cable*

Figure 8 shows the velocity of the piston and cylinder as a function of time for different values of the initial tension, T. The numerical results for both the cylinder and the piston compare very well with experimental values obtained from Hydro-Québec. As expected, the results presented in this graph show that the response of the piston is quite dependent on the value of T. The results presented in Figure 8 also show that as T increases, the maximum piston velocity decreases as would be anticipated. It can be seen that for the range of T used, the piston attained maximum velocities ranging from 19 to 23 m/s. The maximum velocity reached by the cylinder was, as expected, 15 m/s for all values of the tension. The results shown in Figure 8 further shows that as the tension is increased the time the cylinder takes to arrive and

impact the bottom of the piston is also increased. One important other factor that could be observed from Figure 8 is that the negative slope in the piston velocity increases as the tension is increased. This is expected mainly because the mechanical impedance of the cable would increase as the value of the static tension is increased. In this case the mechanical impedance is defined as the opposition of the cable to move relative to the displacement imparted to it by the piston. Best agreement between the simulation and experiment was obtained for T=24 kN.

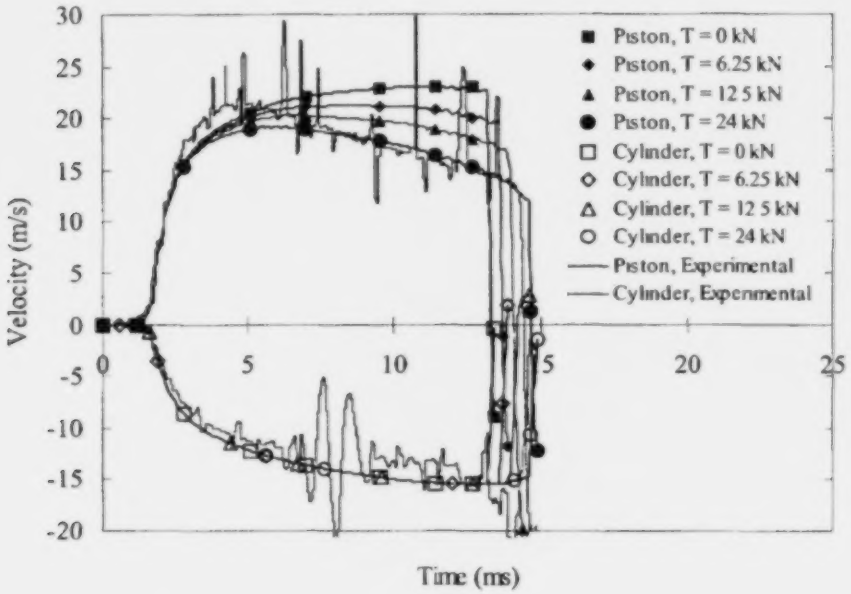

Velocity (m/s)
Time (ms)
Piston, T = 0 kN
Piston, T = 6.25 kN
Piston, T = 12.5 kN
Piston, T = 24 kN
Cylinder, T = 0 kN
Cylinder, T = 6.25 kN
Cylinder, T = 12.5 kN
Cylinder, T = 24 kN
Piston, Experimental
Cylinder, Experimental

Figure 8. *Piston and cylinder velocities as a function of time*

Figure 9 shows the displacement of the cylinder and piston as a function of time for different values of axial tension, T. Here again the numerical results compare quite well with the experimental values. The displacement of the piston ranges from 238 to 215 mm whereas that of the cylinder ranges from 150 to 172 mm.

Figure 10 shows the maximum displacement of the cable at the centre point (shown as B in Fig. &) where the impact of the piston actually occurs. The displacement resembles that of the piston, as expected since the piston is attached rigidly to the cable by the sleeve. Here again the effect of the tension T, was captured quite well.

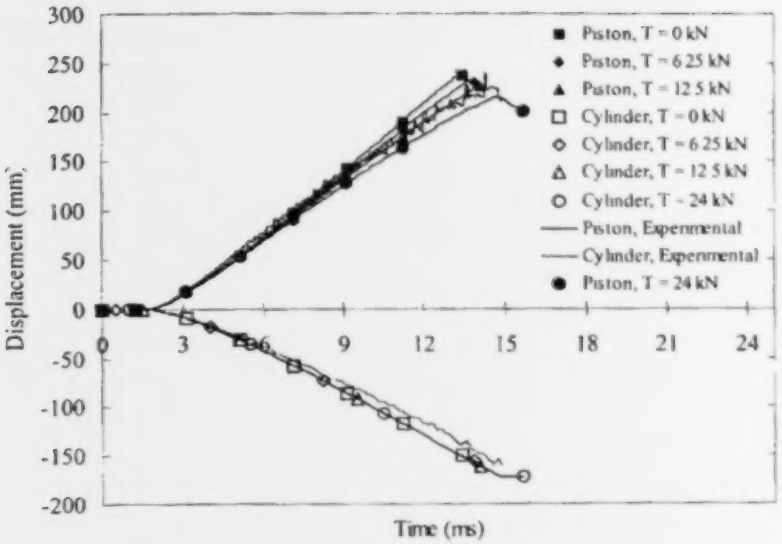

Displacement (mm)
Time (ms)
Piston, T = 0 kN
Piston, T = 6.25 kN
Piston, T = 12.5 kN
Cylinder, T = 0 kN
Cylinder, T = 6.25 kN
Cylinder, T = 12.5 kN
Cylinder, T = 24 kN
Piston, Experimental
Cylinder, Experimental
Piston, T = 24 kN

Figure 9. *Piston and cylinder displacement as a function of time*

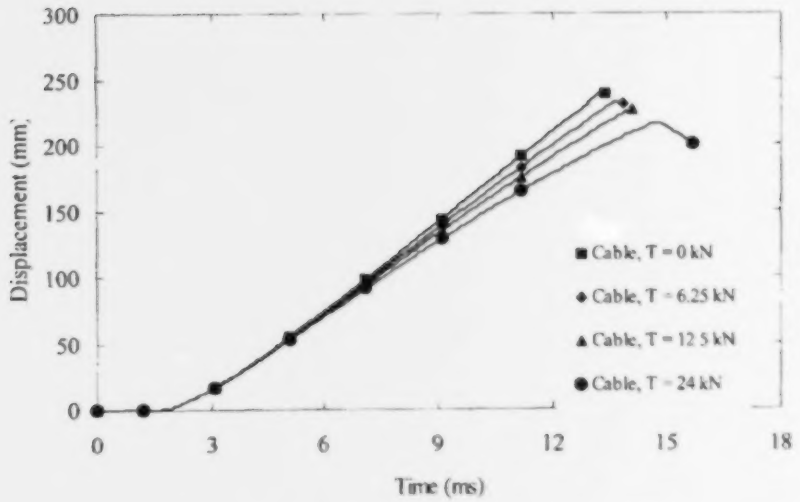


Figure 10. *Cable displacement as a function of time*

An explosive de-icing device concept

Hydro Québec has recognised that the 11.2-kg piston/cylinder prototype de-icing device could be expensive to deploy and use on a routine basis. As a result, discussions led to the investigation of other de-icing device systems that would be less expensive. One idea is a self-detachable device with a small quantity of explosive to supply the energy to displace the cable for de-icing.

1.5 A concept definition

Figure 11 shows the definition of a simple flyer plate explosive concept that could be used to examine the possibility of de-icing a typical guard cable using a limited mass of sheet explosive called Detasheet. This explosive concept consists of a 6061-T6 aluminium plate 20-mm thick, 70-mm by 40-mm that is fitted around the cable as shown in the figure. The material properties for the aluminium used are given in Table 3. The explosive Detasheet is placed on the underside of the steel plate and detonated at the centre point underneath the cable.

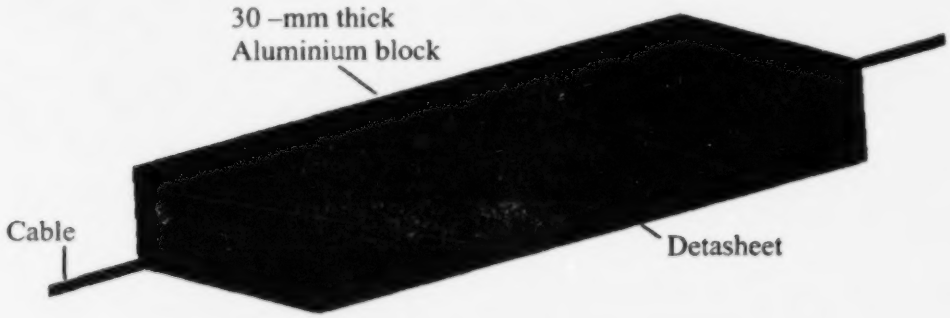


Figure 11. *Flyer plate explosive de-icing device concept using a 1 4-mm thick Detasheet*

Simulations were conducted using three commercially available Detasheet thicknesses. These were 1.4 mm, 2.14 mm and 3.0 mm. Table 4 shows the mass of explosive that was associated with each of the Detasheet thicknesses used. Table 5 shows the material properties and the detonics parameters used to model the high explosive. Explosive properties for the explosive C4 were used for the Detasheet. The arbitrary lagrangian eulerian (ALE) capability in LSDYNA was applied to the model to conduct the simulations. The explosive used an eulerian mesh whereas the rest of the device was modelled using lagrangian meshes. These two meshes were then coupled using the ALE technique.

Table 3. *Material properties for the aluminium used for the explosive concept*

Material Property	Aluminium
Density, ρ (g/cm^3)	2.768
Elastic modulus, E (MPa)	73080
Poisson's ratio, ν	0.34
Elastic limit, σ_y (MPa)	335
Tangent modulus, E_t (MPa)	646
Failure strain, f_s	1.0

Table 4. *Explosive mass for Detasheet thicknesses used*

Detasheet thickness (mm)	Explosive mass (g)
1.40	23
2.13	35
3.00	50

Table 5. *Explosive material properties and detonics parameters*

Explosive property/parameter	Value
Density, ρ (g/mm^3)	1.60
Chapman-Jouget Pressure, PCJ (MPa)	28000
Detonation Velocity, D (mm/ms)	8193
Chapman-Jouget Modulus, E_o (MPa-mm^3/mm^3)	0.303
EOS* parameter, A (MPa)	609770
EOS parameter, B (MPa)	12950
EOS constant, R_1	4.5
EOS constant, R_2	1.4
EOS constant, ω	0.25

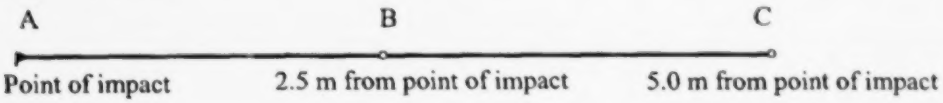
*EOS = Equation of state

1.6 Computational results for the explosive concept

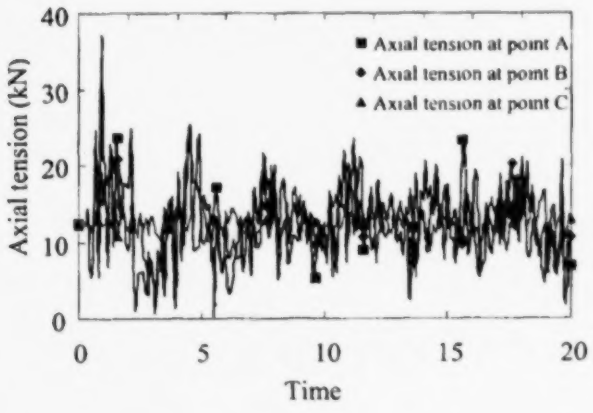
Figure 12 shows a typical example of a simulation that was performed in an effort to obtain the ice free cable response to the impact loading of the explosive de-icing device. In this case the Detasheet thickness use was 1.4 mm.

Figure 12. *Typical simulation performed to examine the cable response to the impact from the flyer plate de-icing device concept*

In all the simulations performed, a pre-tension condition of T = 12.5 kN was applied in the axial direction of the cable. Figure 113 (a) shows three points A, B and C along the axial direction of the cable. Figure 13 (b) shows a typical example of the axial tension, T, of the cable as a function of time at the three points A, B and C. As can be seen the numerical simulations were able capture quite well the effect on the cable tension due to the dynamic loading by the explosively driven plate. It is quite clear that the average axial force was about 12.5 kN as expected but the oscillations caused by the rapid loading are quite large.



(a)



(b)

Figure 13. *Variation of axial tension, T, as a function of time at points A, B and C along the axial direction of the cable*

Figure 14 shows the velocities of the plate as a function of time for three values of Detasheet thickness. The maximum velocity ranges from 32 to 47 m/s as the Detasheet thickness was increased from 1.4 mm to 3.0 mm. The results shown in Figure 14 further demonstrate that as the plate loaded up the cable the maximum velocity was reached within 0.4 ms after which the velocity then started to drop off with a relatively steep negative slope. This negative slope was expected mainly because the mechanical impedance of the cable increases as the axial tension is increased. This rather steep slope could be attributed to the large variation of the axial force shown in Figure 14 which would in turn induced a large mechanical impedance in the cable.

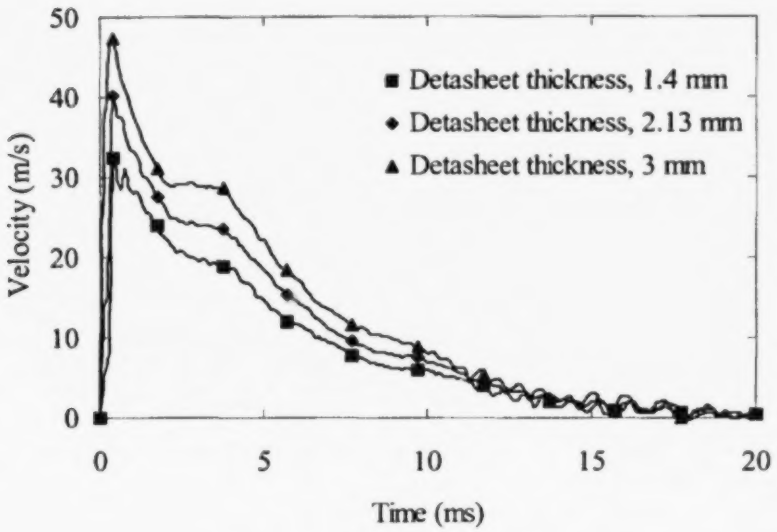


Figure 14. *Cable velocity as a function of time*

Figure 15 shows the displacement of the cable as a function of time. The maximum displacements obtained were 168, 205 and 247 mm for detasheet thicknesses of 1.4, 2.1 and 3.0 mm respectively.

Figure 16 shows the cable maximum displacement as a function of explosive mass. A linear relationship between the maximum displacement and the explosive mass was obtained. The equation for the linear fit is given by $d_{max}=2.92\ m_{exp} + 101.67$ where d_{max} is the maximum displacement in mm and m_{exp} is the explosive mass expressed in g. It is important to note that that the plate area in contact with the Detasheet was kept constant for all the Detasheet thicknesses used.

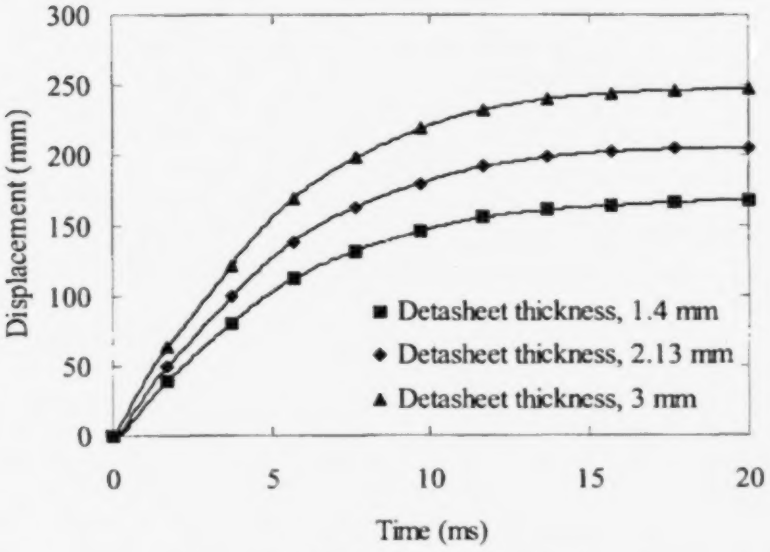


Figure 15. *Cable displacement as a function of time*

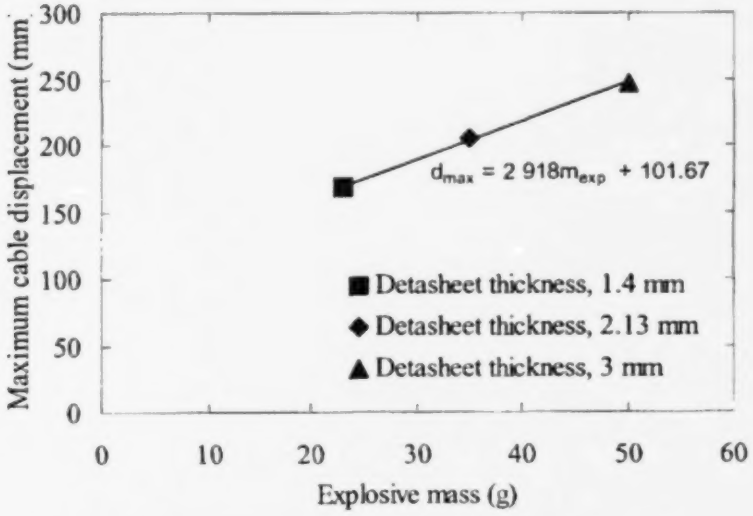


Figure 16. *Maximum cable displacement as function of explosive mass*

Figure 17 compares the velocity response of the explosive device with that of Hydro-Quebec's piston/cylinder prototype. From the graph, it is can be seen that the explosive device loads the cable more rapidly than the piston/cylinder device. This faster loading of the cable could prove to be useful since the rapidly induced shock could be used as a mechanism to help de-ice the cable.

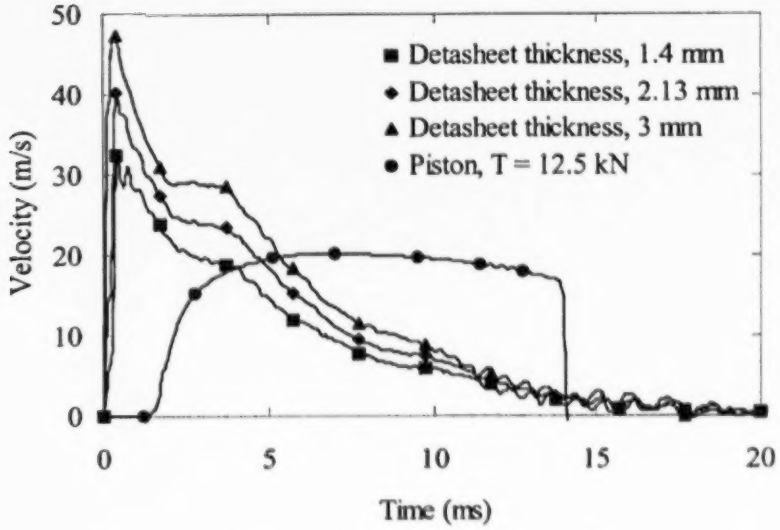


Figure 17. *Comparison of velocity as a function time between the explosive concept and Hydro-Québec's piston/cylinder prototype*

Figure 18 compares the cable displacement response of the explosive concept with that of the piston/cylinder prototype. It can be seen that the piston/cylinder responds less rapidly than the explosive concept. It can be observed that for the piston/cylinder, the cable displacement varies linearly as a function of time up until it reaches its' maximum. On the other hand in the explosive case, the displacement increases rapidly within the first 6 to 10 ms after which it slowly levels off to its maximum displacement.

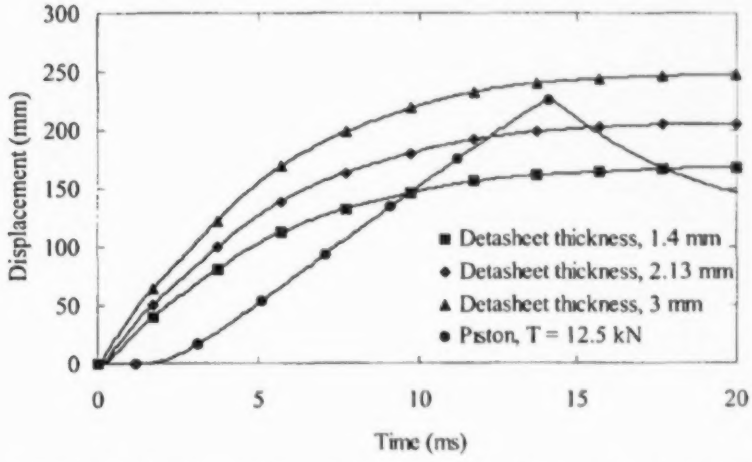


Figure 18. *Comparison of cable displacement as a function time between the explosive concept and Hydro Québec's piston/cylinder prototype*

Conclusion

Numerical simulations of Hydro-Québec's piston/cylinder prototype de-icing device were conducted. The simulations included the pre-tension conditions. The numerical results compared very well with Hydro-Québec's experimental values. The effect of the cable's pre-tension conditions was also well captured extremely well. The numerical results showed that the maximum cable displacement decreases as the magnitude of the static tension is increased. The results further showed that as the magnitude of the static pre-tension is increased the negative slope in the velocity curve after peak velocity is also increased. This indicates that the mechanical impedance of the cable must have also increased. In all cases the maximum displacement of the cylinder was independent of the magnitude of the static pre-tension value as would be expected.

Simulations were also conducted on an explosive concept for de-icing ground cables using a limited mass of explosive called Detasheet. Three thicknesses of Detasheet were used. The numerical results showed that it is possible to displace the cable as much as in the case of the cylinder/piston prototype. It was found that the maximum cable displacement varies linearly with the explosive mass. Comparison of the piston/cylinder prototype and the explosive concept results showed that the piston/cylinder responds less rapidly than the explosive concept. In the piston/cylinder case it was observed that the cable displacement varies almost linearly up until it reaches its maximum. On the other hand, in the explosive case, the displacement increases rapidly within the first 6 to 10 ms after which it slowly levels off at its maximum displacement.

Finally, a comparison of the velocity responses for the two de-icing devices studied shows that in the case of the explosive device the cable loads more rapidly than in the case of the piston/cylinder prototype. This faster loading of the cable could prove to be useful since the induced shock could be used as a mechanism to help de-ice the cable.

Future work and recommendation

The primary objective of the work presented in this report is to conduct numerical simulations of Hydro Québec's piston/cylinder de-icing device and to numerically investigate the feasibility of developing a small explosive de-icing device to be used to de-ice ground cables. Even though the numerical simulations produced excellent results for the piston/cylinder prototype and showed that the explosive concept is capable of producing the same cable displacement, a necessary extension of this work is to experimentally verify the results of the explosive concept.

Another possible concept that needs to be investigated is the use of rocket propellant technology to develop a concept that could possibly be used to propel the cable to its maximum displacement required for it to be de-iced. Work has just been initiated to investigate this possibility.

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List of symbols/abbreviations/acronyms/initialisms

A	Point of impact on cable
ALE	Arbitrary lagrangian eulerian
B, C	2.5 and 5.0 m, respectively, from point of impact
D	Detonation velocity
d_{max}	Maximum displacement
DREV	Defence Research Establishment Valcartier
PCJ	Chapman-Jouget Pressure
E	Elastic modulus
E_o	Chapman-Jouget modulus
EOS	Equation of state
EOS A	Equation of state parameter A
EOS B	Equation of state parameter B
E_t	Tangent modulus
f_s	Failure strain
m_{exp}	Explosive mass
R_1	Equation of state constant
R_2	Equation of state constant
σ_y	Yield stress
T	Static axial tension of cable
ν	Poisson's ratio

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This report summarises numerical analyses performed to predict the responses of Hydro Quebec's piston/cylinder prototype and an explosive flyer plat concept that were both investigated for the de-icing ground cables and electrical lines In the piston/cylinder prototype case, the numerical results obtaine compared very well with the experimental results obtained from Hydro Québec It was shown that the maximum cable displacement decreases as the stati pre-tension value is increased In all cases it was shown that the maximum cylinder displacement remained independent of the cable tension The negativ slope observed in the experimental velocity/time results after the cable has reached its maximum velocity was also captured quite well in the simulations was shown that this negative slope was caused by the increase in the mechanical impedance, which was due to the dynamic effect on the static tension. I the case of the explosive concept, the numerical results showed that it is feasible to use such a system to de-ice cables. Compansons of the results wit those of the piston/cylinder prototype show that the cable responds more rapidly using the explosive concept For the explosive concept it was found tha the maximum displacement of the cable varies linearly with the mass of explosive.

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